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THE PROGRESS OF PHYSICS IN THE NINETEENTH CENTURY.

II.

DIFFRACTION.

Though diffraction dates back to Grimaldi (1665) and was well known to Newton (1704), the first correct though crude interpretation of the phenomenon is due to Young (1802, 1804). Independently Fresnel (1815) in his original work devised similar explanations, but later (1818, 1819, 1826) gave a more rational theory in terms of Huyghens's principle, which he was the first to adequately interpret. Fresnel showed that all points of a wave front are concerned in producing diffraction, though the ultimate critical analysis was left to Stokes (1849).

In 1822 Fraunhofer published his remarkable paper, in which, among other inventions, he introduced the grating into science. Zone plates were studied by Cornu (1875) and by Soret (1875). Rowland's concave grating appeared in 1881. Michelson's echelon spectrometer in 1899.

The theory of gratings and other diffraction phenomena was exhaustively treated by Schwerd (1837). Babinet established the principle bearing his name in 1837. Subsequent developments were in part concerned with the improvement of Fresnel's method of computation, in part with a more rigorous treatment of the theory of diffraction. Stokes (1850, 1852) gave the first account of the polarization accompanying diffraction, and thereafter Rayleigh (1871) and many others, including

Kirchhoff (1882, 1883), profoundly modified the classic treatment. Airy (1834, 1838) and others elaborately examined the diffraction due to a point source in view of its important bearing on the efficiency of optical instruments.

A unique development of diffraction is the phenomenon of scattering propounded by Rayleigh (1871) in his dynamics of the blue sky. This great theory which Rayleigh has repeatedly improved (1881, et seq.) has since superseded all other relevant explanations.

POLARIZATION.

An infinite variety of polarization phenomena grew out of Bartholinus's (1670) discovery. Sound beginnings of a theory were laid by Huyghens ('Traité,' 1690), whose wavelet principle and elementary wave front have persisted as an invaluable acquisition, to be generalized by Fresnel in 1821.

Fresh foundations in this department of optics were laid by Malus (1810) in his discovery of the cosine law and the further discovery of the polarization of reflected light. Later (1815) Brewster adduced the conditions of maximum polarization for this case.

In 1811 Arago announced the occurrence of interferences in connection with parallel plane-polarized light, phenomena which under the observations of Arago and Fresnel (1816, 1819), Biot (1816), Brewster (1813, 1814, 1818) and others grew immensely in variety, and in the importance of their bearing on the undulatory theory. It is on the basis of these phenomena that Fresnel in 1819 insisted on the transversality of light waves, offering proof which was subsequently made rigorous by Verdet (1850). Though a tentative explanation was here again given by Young (1814), the first adequate theory of the behavior of thin plates of aeolotropic media with polarized light came from Fresnel (1821).

Airy (1833) elucidated a special case of the gorgeously complicated interferences obtained with convergent pencils; Neumann in 1834 gave the general theory. The forbidding equations resulting were geometrically interpreted by Bertin (1861, 1884), and Lommel (1883) and Neumann (1841) added a theory for stressed media, afterwards improved by Pockels (1889).

The peculiarly undulatory character of natural light owes its explanation largely to Stokes (1852), and his views were verified by many physicists, notably by Fizeau (1862) showing interferences for path differences of 50,000 wave-lengths and by Michelson for much larger path differences.

The occurrence of double refraction in all non-regular crystals was recognized by Haüy (1788) and studied by Brewster (1818). In 1821, largely by a feat of intuition, Fresnel introduced his generalized elementary wave surface, and the correctness of his explanation has since been substantiated by a host of observers. Stokes (1862, et seq.) was unremittingly active in pointing out the theoretical bearing of the results obtained. Hamilton (1832) supplied a remarkable criterion of the truth of Fresnel's theory deductively, in the prediction of both types of conic refraction. The phenomena were detected experimentally by Lloyd (1833).

The domain of natural rotary polarization, discovered by Arago (1811) and enlarged by Biot (1815), has recently been placed in close relation to non-symmetrical chemical structure by LeBel (1874) and van't Hoff (1875), and a tentative molecular theory was advanced by Sohncke (1876).

Boussinesq (1868) adapted Cauchy's theory (1842) to these phenomena. Independent elastic theories were propounded

by MacCullagh (1837), Briot, Sarrau (1868); but there is naturally no difficulty in accounting for rotary polarization by the electromagnetic theory of light, as was shown by Drude (1892).

Among investigational apparatus of great importance the Soleil (1846, 1847) saccharimeter may be mentioned.

THEORIES.

In conclusion, a brief summary may be given of the chief mechanisms proposed to account for the undulations of light. Fresnel suggested the first adequate optical theory in 1821, which, though singularly correct in its bearing on reflection and refraction in the widest sense, was merely tentative in construction. Cauchy (1829) proposed a specifically elastic theory for the motion of relatively long waves of light in continuous media, based on a reasonable hypothesis of molecular force, and deduced therefrom Fresnel's reflection and refraction equations. Green (1838), ignoring molecular forces and proceeding in accordance with his own method in elastics, published a different theory, which did not, however, lead to Fresnel's equations. Kelvin (1888) found the conditions implied in Cauchy's theory compatible with stability if the ether were considered as bound by a rigid medium. The ether implied throughout is to have the same elasticity everywhere, but to vary in density from medium to medium, and vibration to be normal to the plane of polarization.

Neumann (1835), whose work has been reconstructed by Kirchhoff (1876), and MacCullagh (1837), with the counter-hypothesis of an ether of fixed density but varying in elasticity from medium to medium, also deduced Fresnel's equations, obtaining at the same time better surface conditions in the case of æolotropic media. The vibrations are in the plane of polarization.

All the elastic theories essentially predict a longitudinal light wave. It was not until Kelvin in 1889, 1890 proposed his remarkable gyrostatic theory of light, in which force and displacement become torque and twist, that these objections to the elastic theory were wholly removed. MacCullagh, without recognizing their bearing, seems actually to have anticipated Kelvin's equation.

With the purpose of accounting for dispersion, Cauchy in 1835 gave greater breadth to his theory by postulating a sphere of action of ether particles commensurate with wave-length, and in this direction he was followed by F. Neumann (1841), Briot (1864), Rayleigh (1871) and others, treating an ether variously loaded with material particles. Among theories beginning with the phenomena observed, that of Boussinesq (1867, et seq.) has received the most extensive development.

The difficult surface conditions met with when light passes from one medium to another, including such subjects as ellipticity, total reflection, etc., have been critically discussed, among others, by Neumann (1835) and Rayleigh (1888); but the discrimination between the Fresnel and the Neumann vector was not accomplished without misgiving before the advent of the work of Hertz.

It appears, therefore, that the elastic theories of light, if Kelvin's gyrostatic adynamic ether be admitted, have not been wholly routed. Nevertheless, the great electromagnetic theory of light propounded by Maxwell (1864, 'Treatise,' 1873) has been singularly apt not only in explaining all the phenomena reached by the older theories and in predicting entirely novel results, but in harmoniously uniting as parts of a unique doctrine, both the electric

or photographic light vector of Fresnel and Cauchy and the magnetic vector of Neumann and MacCullagh. Its predictions have, moreover, been astonishingly verified by the work of Hertz (1890), and it is to-day acquiring added power in the convection theories of Lorentz (1895) and others.

ELECTROSTATICS.

Coulomb's (1785) law antedates the century; indeed, it was known to Cavendish (1771, 1781). Problems of electric distribution were not seriously approached, however, until Poisson (1811) solved the case for spheres in contact. Afterwards Clausius (1852), Helmholtz (1868) and Kirchhoff (1877) examined the conditions for discs, the last giving the first rigorous theory of the experimentally important plate condenser. In 1845, 1848 the investigation of electric distribution received new incentive as an application of Kelvin's beautiful method of images. Maxwell ('Treatise,' 1873) systematized the treatment of capacity and induction coefficients.

Riess (1837) in a classic series of experiments on the heat produced by electrostatic discharge virtually deduced the potential energy of a conductor and in a measure anticipated Joule's law (1841). In 1860 appeared Kelvin's great paper on the electromotive force needed to produce a spark. As early as 1855, however, he had shown that the spark discharge is liable to be of the character of a damped vibration and the theory of electric oscillation was subsequently extended by Kirchhoff (1867). The first adequate experimental verification is due to Feddersen (1858, 1861).

The specific inductive capacity of a medium with its fundamental bearing on the character of electric force was discovered by Faraday in 1837. Of the theories propounded to account for this property the most far reaching is Maxwell's (1865), which culminates in the unique result showing that the refraction index of a medium is the square root of its specific inductive capacity. With regard to Maxwell's theory of the Faraday stress in the ether as compared with the subsequent development of electrostriction in other media by many authors, notably by Boltzmann (1880) and by Kirchhoff (1885), it is observable that the tendency of the former to assign concrete physical properties to the tube of force is growing, particularly in connection with radioactivity. Duhem (1892, 1895) insists, however, on the greater trustworthiness of the thermodynamic potential.

The seemingly trivial subject of pyroelectricity interpreted by Æpinus (1756) and studied by Brewster (1825), has none the less elicited much discussion and curiosity, a vast number of data by Hankel (1839–93) and others and a succinct explanation by Kelvin (1860, 1878). Similarly piezoelectricity, discovered by the brothers Curie (1880), has been made the subject of a searching investigation by Voigt (1890). Finally Kerr (1875, et seq.) observed the occurrence of double refraction in an electrically polarized medium. Recent researches, among which those of Lemoine (1896) are most accurate, have determined the phase difference corresponding to the Kerr effect under normal conditions, while Voigt (1899) has adduced an adequate theory.

Certain electrostatic inventions have had a marked bearing on the development of electricity. We may mention in particular Kelvin's quadrant electrometer (1867) and Lippmann's capillary electrometer (1873). Moreover, among apparatus originating in Nicholson's duplicator (1788) and Volta's electrophorus, the Töpler-Holtz machine (1865–67), with the recent improvement due to Wimshurst, has

replaced all others. Atmospheric electricity, after the memorable experiment of Franklin (1751), made little progress until Kelvin (1860) organized a systematic attack. More recently a revival of interest began with Exner (1886), but more particularly with Linss (1887), who insisted on the fundamental importance of a detailed knowledge of atmospheric conduction. It is in this direction that the recent vigorous treatment of the atmosphere as an ionized medium has progressed, owing chiefly to the indefatigable devotion of Elster and Geitel (1899, et seq.) and of C. T. R. Wilson (1897, et seq.). Qualitatively the main phenomena of atmospheric electricity are now plausibly accounted for; quantitatively there is as yet very little specific information.

VOLTA CONTACTS.

Volta's epoch-making experiment of 1797 may well be added to the century which made such prolific use of it; indeed, the Voltaic pile (1800–02) and Volta's law of series (1802) come just within it. Among the innumerable relevant experiments Kelvin's dropping electrodes (1859) and his funnel experiment (1867) are among the more interesting, while the 'Spannungsreihe' of R. Kohlrausch (1851, 1853) is the first adequate investigation. Nevertheless, the phenomenon has remained without a universally acceptable explanation until the present day, when it is reluctantly yielding to electronic theory, although ingenious suggestions like Helmholtz's 'Doppelschicht' (1879), the interpretations of physical chemistry and the discovery of the concentration cell (Helmholtz; Nernst, 1888, 1889; Planck, 1890) have thrown light upon it.

Among the earliest theories of the galvanic cell is Kelvin's (1851, 1860), which, like Helmholtz's, is incomplete. The most satisfactory theory is Nernst's (1889). Gibbs (1878) and Helmholtz (1882) have made searching critical contributions, chiefly in relation to the thermal phenomena.

Volta's invention was made practically efficient in certain famous galvanic cells, among which Daniell's (1836), Grove's (1839), Clarke's (1878), deserve mention, and for the purposes of measurement have been subserved by the potentiometers of Poggendorff (1841), Bosscha (1855), Clarke (1873).

SEEBECK CONTACTS.

Thermoelectricity, destined to advance many departments of physics, was discovered by Seebeck in 1821. The Peltier effect followed in 1834, subsequently to be interpreted by Icilius (1853). A thermodynamic theory of the phenomena came from Clausius (1853) and with greater elaboration, together with the discovery of the Thomson effect, from Kelvin (1854, 1856), to whom the thermoelectric diagram is due. This was subsequently developed by Tait (1872, et seq.) and his pupils. Avenarius (1863), however, first observed the thermoelectric parabola.

The modern platinum-iridium or platinum-rhodium thermoelectric pyrometer dates from about 1885 and has recently been perfected at the Reichsanstalt. Melloni (1835, et seq.) made the most efficient use of the thermopyle in detecting minute temperature differences.

ELECTROLYSIS.

Though recognized by Nichols and Carlisle (1800) early in the century, the laws of electrolysis awaited the discovery of Faraday (1834). Again, it was not till 1853 that further marked advances were made by Hittorf's (1853–59) strikingly original researches on the velocities of the ions. Later Clausius (1857) suggested an adequate theory of electrolysis, which was

subsequently to be specialized in the dissociation hypothesis of Arrhenius (1881, 1884). To the elaborate investigations of F. Kohlrausch (1879, et seq.), however, science owes the fundamental law of the independent velocities of migration of the ions.

Polarization discovered by Ritter in 1803 became in the hands of Plante (1859–1879) an invaluable means for the storage of energy, an application which was further improved by Faure (1880).

STEADY FLOW.

The fundamental law of the steady flow of electricity, in spite of its simplicity, proved to be peculiarly elusive. True, Cavendish (1771–81) had definite notions of electrostatic resistance as dependent on length section and potential, but his intuitions were lost to the world. Davy (1820), from his experiments on the resistances of conductors, seems to have arrived at the law of sections, though he obscured it in a misleading statement. Barlow (1825) and Becquerel (1825–26), the latter operating with the ingenious differential galvanometer of his own invention, were not more definite. Surface effects were frequently suspected. Ohm himself, in his first paper (1825), confused resistance with the polarization of his battery, and it was not till the next year (1826) that he discovered the true law, eventually promulgated in his epoch-making 'Die galvanische Kette' (1827).

It is well known that Ohm's mathematical deductions were unfortunate, and would have left a gap between electrostatics and voltaic electricity. But after Ohm's law had been further experimentally established by Fechner (1830), the correct theory was given by Kirchhoff (1849) in a way to bridge over the gap specified. Kirchhoff approached the question gradually, considering first the distribution of current in a plane conductor (1845–1846), from which he passed to the laws of distribution in branched conductors (1847–48)—laws which now find such universal application. In his great paper, moreover, Kirchhoff gives the general equation for the activity of the circuit and from this Clausius (1852) soon after deduced the Joule effect theoretically. The law, though virtually implied in Riess's results (1837), was experimentally discovered by Joule (1841).

As bearing critically or otherwise on Ohm's law we may mention the researches of Helmholtz (1852), of Maxwell (1876), the solution of difficult problems in regard to terminals or of the resistance of special forms of conductors, by Rayleigh (1871, 1879), Hicks (1883) and others, the discussion of the refraction of lines of flow by Kirchhoff (1845), and many researches on the limits of accuracy of the law.

Finally, in regard to the evolution of the modern galvanometer from its invention by Schweigger (1820), we may enumerate in succession Nobili's astatic system (1834), Poggendorff's (1826) and Gauss's (1833) mirror device, the aperiodic systems, Weber's (1862) and Kelvin's critical study of the best condition for galvanometry, so cleverly applied in the instruments of the latter. Kelvin's siphon recorder (1867), reproduced in the Depretz-D'Arsonval system (1882), has adapted the galvanometer to modern conditions in cities. For absolute measurement Pouillet's tangent galvanometer (1837), treated for absolute measurement by Weber (1840), and Weber's dynamometer (1846) have lost little of their original importance.

MAGNETISM.

Magnetism, definitely founded by Gilbert (1600) and put on a quantitative basis by Coulomb (1785), was first made the subject of recondite theoretical treatment by

Poisson (1824–27). The interpretation thus given to the mechanism of two conditionally separable magnetic fluids facilitated discussion and was very generally used in argument, as for instance by Gauss (1833) and others, although Ampère had suggested the permanent molecular current as early as 1820. Weber (1852) introduced the revolable molecular magnet, a theory which Ewing (1890) afterwards generalized in a way to include magnetic hysteresis. The phenomenon itself was independently discovered by Warburg (1881) and by Ewing (1882) and has since become of special practical importance.

Faraday in 1852 introduced his invaluable conception of lines of magnetic force, a geometric embodiment of Gauss's (1813, 1839) theorem of force flux, and Maxwell (1855, 1862, et seq.) thereafter gave the rigorous scientific meaning to this conception, which pervades the whole of cotemporaneous electromagnetics.

The phenomenon of magnetic induction, treated hypothetically by Poisson (1824–27) and even by Barlow (1820), has since been attacked by many great thinkers, like F. Neumann (1848), Kirchhoff (1854); but the predominating and most highly elaborated theory is due to Kelvin (1849, et seq.). This theory is broad enough to be applicable to æolotropic media and to it the greater part of the notation in current use throughout the world is due. A new method of attack of great promise has, however, been introduced by Duhem (1888, 1895, et seq.) in his application of the thermodynamic potential to magnetic phenomena.

Magneticians have succeeded in expressing the magnetic distribution induced in certain simple geometrical figures like the sphere, the spherical shell, the ellipsoid, the infinite cylinder, the ring. Green in 1828 gave an original but untrustworthy treatment for the finite cylinder. Lamellar and solenoidal distributions are defined by Kelvin (1850), to whom the similarity theorems (1856) are also due. Kirchhoff's results for the ring were practically utilized in the absolute measurements of Stoletow (1872) and of Rowland (1878).

Dimagnetism, though known since Brugmans (1778), first challenged the permanent interest of science in the researches of Becquerel (1827) and of Faraday (1845). It is naturally included harmoniously in Kelvin's great theory (1847, et seq.). Independent explanations of diamagnetism, however, have by no means abandoned the field; one may instance Weber's (1852) ingenious generalization of Ampère's molecular currents (1820) and the broad critical deductions of Duhem (1889) from the thermodynamic potential. For the treatment of æolotropic magnetic media, Kelvin's (1850, 1851) theory seems to be peculiarly applicable. Weber's theory would seem to lend itself well to electronic treatment.

The extremely complicated subject of magnetostriction, originally observed by Matteuci (1847) and by Joule (1849) in different cases, and elaborately studied by Wiedemann (1858, et seq.), has been repeatedly attacked by theoretical physicists, among whom Helmholtz (1881), Kirchhoff (1885), Boltzmann (1879) and Duhem (1891) may be mentioned. None of the carefully elaborated theories accounts in detail for the facts observed.

The relations of magnetism to light have increased in importance since the fundamental discoveries of Faraday (1845) and of Verdet (1854), and they have been specially enriched by the magneto-optic discoveries of Kerr (1876, et seq.), of Kundt (1884, et seq.), and more recently by the Zeemann effect (1897, et seq.). Among the theories put forth for the latter, the electronic explanation of Lorentz (1898, 1899) and that of Voigt (1899) are

supplementary or at least not contradictory. The treatment of the Kerr effect has been systematized by Drude (1892, 1893). The instantaneity of the rotational effect was first shown by Bichat and Blondlot (1882) and this result has since been found useful in chronography. Sheldon demonstrated the possibility of reversing the Faraday effect. Finally terrestrial magnetism was revolutionized and made accessible to absolute measurement by Gauss (1833), and his method served Weber (1840, et seq.) and his successors as a model for the definition of absolute units throughout physics. Another equally important contribution from the same great thinker (1840) is the elaborate treatment of the distribution of terrestrial magnetism, the computations of which have been twice modernized, in the last instance by Neumeyer[1] (1880). Magnetometric methods have advanced but little since the time of Gauss (1833), and Weber's (1853) earth inductor remains a standard instrument of research. Observationally, the development of cycles of variation in the earth's constants is looked forward to with eagerness, and will probably bear on an adequate theory of terrestrial magnetism, yet to be framed. Arrhenius (1903) accentuates the importance of the solar cathode torrent in its bearing on the earth's magnetic phenomena.

ELECTROMAGNETISM.

Electromagnetism considered either in theory or in its applications is, perhaps, the most conspicuous creation of the nineteenth century. Beginning with Oersted's great discovery of 1820, the quantitative measurements of Biot and Savart (1820) and Laplace's (1821) law followed in quick succession. Ampère (1820) without delay propounded his famous theory of magnetism. For many years the science was conveniently subserved by Ampère's swimmer (1820), though his functions have since advantageously yielded to Fleming's hand rule for moving current elements. The induction produced by ellipsoidal coils or the derivative cases is fully understood. In practise the rule for the magnetic circuit devised by the Hopkinsons (1886) is in general use. It may be regarded as a terse summary of the theories of Euler (1780), Faraday, Maxwell and particularly Kelvin (1872), who already made explicit use of it. Nevertheless, the clear-cut practical interpretation of the present day had to be gradually worked out by Rowland (1873, 1884), Bosanquet (1883–85), Kapp (1885) and Pisati (1890).

The construction of elementary motors was taken up by Faraday (1821), Ampère (1822), Barlow (1822) and others, and they were treated rather as laboratory curiosities; for it was not until 1857 that Siemens devised his shuttle wound armature and the development of the motor thereafter went *pari passu* with the dynamo to be presently considered. It culminated in a new principle in 1888 when Ferraris, and somewhat later Tesla (1888) and Borel (1888), introduced polyphase transmission and the more practical realization of Arago's rotating magnetic field (1824).

Theoretical electromagnetics, after a period of quiescence, was again enriched by the discovery of the Hall effect (1879, et seq.), which at once elicited wide and vigorous discussion, and for which Rowland (1880), Lorentz (1883), Boltzmann (1886) and others put forward theories of continually increasing finish. Nernst and V. Ettingshausen (1886, 1887) afterwards added the thermomagnetic effect.

[1] Dr. L. A. Bauer kindly called my attention to the more recent work of A. Schmidt, summarized in Dr. Bauer's own admirable paper.

ELECTRODYNAMICS.

The discovery and interpretation of electrodynamic phenomena were the burden of the unique researches of Ampère (1820, et seq., 'Memoir,' 1826). Not until 1846, however, were Ampère's results critically tested. This examination came with great originality from Weber using the bifilar dynamometer of his own invention. Grassmann (1845), Maxwell (1873) and others have invented elementary laws differing from Ampère's; but as Stefan (1869) showed that an indefinite number of such laws might be constructed to meet the given integral conditions, the original law is naturally preferred.

INDUCTION.

Faraday (1831, 1832) did not put forward the epoch-making discovery of electrokinetic induction in quantitative form, as the great physicist was insufficiently familiar with Ohm's law. Lentz, however, soon supplied the requisite interpretation in a series of papers (1833, 1835) which contain his well-known law both for the mutual inductions of circuits and of magnets and circuits. Lentz clearly announced that the induced quantity is an electromotive force, independent of the diameter and metal and varying, *cæt. par.*, with the number of spires. The mutual induction of circuits was first carefully studied by Weber (1846), later by Filici (1852), using a zero method, and Faraday's self-induction by Edlund (1849), while Matteuci (1854) attested the independence of induction of the interposed non-magnetic medium. Henry (1842) demonstrated the successive induction of induced currents.

Curiously enough the occurrence of eddy currents in massive conductors moving in the magnetic field was announced from a different point of view by Arago (1824–26) long before Faraday's great discovery. They were but vaguely understood, however, until Foucault (1855) made his investigation. The general problem of the induction to be anticipated in massive conductor is one of great interest and Helmholtz (1870), Kirchhoff (1891), Maxwell (1873), Hertz (1880) and others have treated it for different geometrical figures.

The rigorous expression of the law of induction was first obtained by F. Neumann (1845, 1847) on the basis of Lentz's law, both for circuits and for magnets. W. Weber (1846) deduced the law of induction from his generalized law of attraction. More acceptably, however, Helmholtz (1847), and shortly after him Kelvin (1848), showed the law of induction to be a necessary consequence of the law of the conservation of energy, of Ohm's and Joule's law. In 1851 Helmholtz treated the induction in branched circuits. Finally Faraday's 'electrotonic state' was mathematically interpreted thirty years later, by Maxwell, and to-day, under the name of electromagnetic momentum, it is being translated into the notation of the electronic theory.

Many physicists following the fundamental equation of Neumann (1845, 1847) have developed the treatment of mutual and self induction with special reference to experimental measurement.

On the practical side the magneto-inductor may be traced back to d'al Negro (1832) and to Pixii (1832). The tremendous development of induction electric machinery which followed the introduction of Siemens's (1857) armature can only be instanced. In 1867 Siemens, improving upon Wilde (1866), designed electric generators without permanent magnets. Pacinotti (1860) and later Gramme (1871) invented the ring armature, while von Hefner-Alteneck (1872) and others improved the drum armature. Thereafter further progress was rapid.

It took a different direction in connec-

tion with the Ferraris (1888) motor by the development of the induction coil of the laboratory (Faraday, 1831; Neef, 1839; Ruhmkoff, 1853) into the transformer (Gaulard and Gibbs, 1882–84) of the arts. Among special apparatus Hughes (1879) contributed the induction balance and Tesla (1891) the high frequency transformer. The Elihu Thompson effect (1887) has also been variously used.

In 1860 Reiss devised a telephone in a form, however, not at once capable of practical development. Bell in 1875 invented a different instrument which needed only the microphone (1878) of Hughes and others to introduce it permanently into the arts. Of particular importance in its bearing on telegraphy, long associated with the names of Gauss and Weber (1833) or practically with Morse and Vail (1837), is the theory of conduction with distributed capacity and inductance established by Kelvin (1856) and extended by Kirchhoff (1857). The working success of the Atlantic cable demonstrated the acumen of the guiding physicist.

ELECTRIC OSCILLATION.

The subject of electric oscillation announced in a remarkable paper of Henry in 1842 and threshed out in its main features by Kelvin in 1856, followed by Kirchhoff's treatment of the transmission of oscillations along a wire (1857), has become of discriminating importance between Maxwell's theory of the electric field and the other equally profound theories of an earlier date. These crucial experiments contributed by Hertz (1887, et seq.) showed that electromagnetic waves move with the velocity of light, and like it are capable of being reflected, refracted, brought to interference and polarized. A year later Hertz (1888) worked out the distribution of the vectors in the space surrounding the oscillatory source. Lecher (1890) using an ingenious device of parallel wires, Blondlot (1891) with a special oscillator, and with greater accuracy Trowbridge and Duane (1895) and Saunders (1896), further identified the velocity of the electric wave with that of the wave of light. Simultaneously the reasons for the discrepancies in the strikingly original method for the velocity of electricity due to Wheatstone (1834), and the American and other longitude observations (Walker, 1894; Mitchell, 1850; Gould, 1851), became apparent, though the nature of the difficulties had already appeared in the work of Fizeau and Gounelle (1850).

Some doubt was thrown on the details of Hertz's results by Sarasin and de la Rive's phenomenon of multiple resonance (1890), but this was soon explained away as the necessary result of the occurrence of damped oscillations by Poincaré (1891), by Bjerknes (1891) and others. J. J. Thomson (1891), contributed interesting results for electrodeless discharges, and on the value of the dielectric constant for slow oscillations (1889); Boltzmann (1893) examined the interferences due to thin plates; but it is hardly practicable to summarize the voluminous history of the subject. On the practical side, we are to-day witnessing the astoundingly rapid growth of Hertzian wave wireless telegraphy, due to the successive inventions of Branly (1890, 1891), Popoff, Braun (1899) and the engineering prowess of Marconi. In 1901 these efforts were crowned by the incredible feat of Marconi's first message from Poldhu to Cape Breton, placing the old world within electric earshot of the new.

Maxwell's equations of the electromagnetic field were put forward as early as 1864, but the whole subject is presented in its broadest relations in his famous treatise of 1873. The fundamental feature of Maxwell's work is the recognition of the displacement current, a conception by

which Maxwell was able to annex the phenomena of light to electricity. The methods by which Maxwell arrived at his great discoveries are not generally admitted as logically binding. Most physicists prefer to regard them as an invaluable possession as yet unliquidated in logical coin; but of the truth of his equations there is no doubt. Maxwell's theory has been frequently expounded by other great thinkers, by Rayleigh (1881), by Poincaré (1890), by Boltzmann (1890), by Heaviside (1889), by Hertz (1890), by Lorentz and others. Hertz and Heaviside, in particular, have condensed the equations into the symmetrical form now commonly used. Poynting (1884) contributed his remarkable theorem on the energy path.

Prior to 1870 the famous law of Weber (1846) had gained wide recognition, containing as it did Coulomb's law, Ampère's law, Laplace's law, Neumann's law of induction, the conditions of electric oscillation and of electric convection. Every phenomenon in electricity was deducible from it compatibly with the doctrine of the conservation of energy. Clausius (1878), moreover, by a logical effort of extraordinary vigor established a similar law. Moreover, the early confirmation of Maxwell's theory in terms of the dielectric constant and refractive index of the medium was complex and partial. Rowland's (1876, 1889) famous experiment of electric convection, which has recently been repeatedly verified by Pender and Cremieu and others, though deduced from Maxwell's theory, is not incompatible with Weber's view. Again the ratio between the electrostatic and the electromagnetic system of units, repeatedly determined from the early measurement of Maxwell (1868) to the recent elaborate determinations of Abraham (1892) and Margaret Maltby (1897), with an ever closer approach to the velocity of light, was at its inception one of the great original feats of measurement of Weber himself associated with Kohlrausch (1856). The older theories, however, are based on the so-called action at a distance or on the instantaneous transmission of electromagnetic force. Maxwell's equations, while equally universal with the preceding, predicate not merely a finite time of transmission, but transmission at the rate of the velocity of light. The triumph of this prediction in the work of Hertz has left no further room for reasonable discrimination.

As a consequence of the resulting enthusiasm, perhaps, there has been but little reference in recent years to the great investigation of Helmholtz (1870, 1874), which includes Maxwell's equations as a special case; nor to his later deduction (1886, 1893) of Hertz's equations from the principle of least action. Nevertheless, Helmholtz's electromagnetic potential is deduced rigorously from fundamental principles and contains, as Duhem (1901) showed, the electromagnetic theory of light.

Maxwell's own vortex theory of physical lines of force (1861, 1862) probably suggested his equations. In recent years, however, the efforts to deduce them directly from apparently simpler properties of a continuous medium, as for instance from its ideal elastics, or again from a specialized ether, have not been infrequent. Kelvin (1890) with his quasi-rigid ether, Boltzmann (1893), Sommerfeld (1892) and others have worked efficiently in this direction. On the other hand, J. J. Thomson (1891, et seq.), with remarkable intuition, affirms the concrete physical existence of Faraday tubes of force, and from this hypothesis reaches many of his brilliant predictions on the nature of matter.

As a final commentary on all these divers interpretations, the important dictum of

Poincaré should not be forgotten: If, says Poincaré, compatibly with the principle of the conservation of energy and of least action, any single ether mechanism is a possibility, there must at the same time be an infinity of others.

THE ELECTRONIC THEORY.

The splendid triumph of the electronic theory is quite of recent date, although Davy discovered the electric arc in 1821 and although many experiments were made on the conduction of gases by Faraday (1838), Riess, Gassiot (1858, et seq.) and others. The marvelous progress which the subject has made begins with the observations of the properties of the cathode ray by Plücker and Hittorf (1868), brilliantly substantiated and extended later by Crookes (1879). Hertz (1892) and more specifically Lenard (1894) observed the passage of the cathode rays into the atmosphere. Perrin (1895) showed them to be negatively charged, Röntgen (1895) shattered them against a solid obstacle generating the X-ray. Goldstein (1886) discovered the anodal rays.

Schuster's (1890) original determination of the charge carried by the ion per gram was soon followed by others utilizing both the electrostatic and the magnetic deviation of the cathode torrent and by Lorentz (1895) using the Zeeman effect. J. J. Thomson (1898) succeeded in measuring the charge per corpuscle and its mass, and the velocities following Thomson (1897) and Wiechert (1899), are known under most varied conditions.

But all this rapid advance, remarkable in itself, became startlingly so when viewed correlatively with the new phenomena of radioactivity, discovered by Becquerel (1896), wonderfully developed by M. and Madame Curie (1898, et seq.), by J. J. Thomson and his pupils, particularly by Rutherford (1899, et seq.). From the Curies came radium (1898) and the thermal effect of radioactivity (1903), from Thomson much of the philosophical prevision which revealed the lines of simplicity and order in a bewildering chaos of facts, and from Rutherford the brilliant demonstration of atomic disintegration (1903) which has become the immediate trust of the twentieth century. Even if the ultimate significance of such profound researches as Larmor's (1891) 'Ether and Matter' can not yet be discerned, the evidences of the transmutation of matter are assured, and it is with these that the century will immediately have to reckon.

The physical manifestations accompanying the breakdown of atomic structure, astoundingly varied as these prove to be, assume fundamental importance when it appears that the ultimate issue involved is nothing less than a complete reconstruction of dynamics on an electromagnetic basis. It is now confidently affirmed that the mass of the electron is wholly of the nature of electromagnetic inertia, and hence, as Abraham (1902), utilizing Kaufmann's data (1902) on the increase of electromagnetic mass with the velocity of the corpuscle, has shown, the Lagrangian equations of motion may be recast in an electromagnetic form. This profound question has been approached independently by two lines of argument, one beginning with Heaviside (1889), who seems to have been the first to compute the magnetic energy of the electron, J. J. Thomson (1891, 1893), Morton (1896), Searle (1896), Sutherland (1899); the other with H. A. Lorentz (1895), Wiechert (1898, 1899), Des Coudres (1900), Drude (1900), Poincaré (1900), Kaufmann (1901), Abraham (1902). Not only does this new electronic tendency in physics give an acceptable account of heat, light, the X-ray, etc., but of the Lagrangian function and of Newton's laws.

Thus it appears even in the present necessarily superficial summary of the progress of physics within one hundred years, that, curiously enough, just as the nineteenth century began with dynamics and closed with electricity, so the twentieth century begins anew with dynamics to reach a goal the magnitude of which the human mind can only await with awe. If no Lagrange stands toweringly at the threshold of the era now fully begun, superior workmen abound in continually increasing numbers, endowed with insight, adroitness, audacity and resources, in a way far transcending the early visions of the wonderful century which has just closed.

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SCIENTIFIC BOOKS.

Civil Engineering, A Text-book for a Short Course. By Lieut.-Col. G. J. FIEBERGER, U. S. Army, Professor of Engineering, U. S. Military Academy, M. Am. Soc. C. E.

It is not easy to rate the book under discussion at its true value. The tendency of engineering education of the present day is towards elaborate presentation of the several phases of engineering practise and if there is any reaction from the excessive development of so-called specialties, it shows itself in a greater concentration on elementary mechanics and other fundamentals.

When engineering education was in its infancy and when the science was being formulated, Rankine, in his famous and classic book, developed and put together all that was known on the subject. Since then, the science and knowledge of engineering have grown so rapidly and extensively that, in spite of a generous appreciation of the work of Rankine, one is startled at a present-day attempt to compress modern engineering knowledge into a single volume of less than six hundred pages.

The author explains that the book is intended to give the military cadets, who have to master many sciences and languages as well as military science and tactics, an elementary knowledge of civil engineering. To properly rate the value of the book, for its avowed purpose, this condition must be kept in mind and any comparison with other separate volumes, used in technical schools, must be carefully avoided.

About one third of the book is devoted to the mechanics of materials, and all ordinary problems of strength in flexure, tension, compression and torsion are given. Fifty numerical problems, about one to every four pages, are given to fix the principles stated, and additional illustrative problems are said to be used in the class room.

Thirty-four pages are given to hydraulics and seventy pages to bridge stresses, making one half of the book devoted to fundamental theory. While this theory is admirably presented, the principles and hypotheses carefully stated, however condensed, the writer can not help feeling that the average student mind is too immature to successfully assimilate such highly concentrated food, and further, he believes that much fundamental theory has been omitted. For example, in hydraulics no problems involving the time of emptying locks or reservoirs are given, no formulæ for velocity of approach for weirs and no discussion of submerged weirs. Yet space is taken for full algebraic development of equations of moment for continuous beams over four and even five supports.

Materials of construction, stone, cement, steel, iron, etc., are discussed to the extent of sixty pages. It is surprising, in view of the thousands of tons of Bessemer steel used annually in buildings, to read that 'open hearth steel is preferred by engineers for structural work,' while 'Bessemer steel is largely used for steel railway rails,' and further that 'cast-iron struts in the form of hollow columns are employed in structures not subjected to the shocks of suddenly applied loads.' In the description of brick, but ten lines are devoted to paving brick and the young officers are there told that paving brick are tested in a rattler used for castings or by dropping the brick repeatedly on a hard floor. It would have required so few additional lines to have